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TECHNICAL REPORT

U.S. NAVY HYDROGRAPHIC OFFICE SYNOPTIC AND PROGNOSTIC WAVE CHARTS

JOHN J. SCHULE, JR.
and
JOHN F. ROPEK
Applied Oceanography Branch
Division of Oceanography

MAY 1955

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no.TR-16

U. S. NAVY HYDROGRAPHIC OFFICE
WASHINGTON, D. C.

ABSTRACT

This report describes a new method for presenting wave conditions over a large area. Techniques for preparing both synoptic and prognostic wave charts are presented, and some of the problems encountered in analysis are discussed. Since these wave charts can be transmitted by radio facsimile, they are ideally suited for operational use.

In addition, a series of synoptic charts and 24-hour prognostic charts as well as recommendations for further developmental work are included.

FOREWORD

Up-to-date information on sea conditions over large areas of the ocean would be of value to most types of naval operations. Thus, in recent years, considerable research has been devoted to the development of prediction techniques and methods of presenting wave forecasts to the operational forces.

Standard methods for observing, reporting, and predicting wave conditions have been described in publications issued by the Hydrographic Office. But, as more is learned about the behavior of the sea surface and as more data become available, new techniques for applying wave forecasts to operational problems are necessary. In order for this type of developmental work to continue, accurate wave observations and evaluations of forecasting methods from ships are extremely important. The methods of presentation described in this report are not known to be in use at the present time, and the wave charts are still in the developmental stage. The Hydrographic Office welcomes comments as to their construction and operational value.

J. B. COCHRAN
Captain, U. S. Navy
Hydrographer

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A. INTRODUCTION

The Hydrographic Office Wave Charts are an attempt to present ocean wave conditions synoptically over a large ocean area. Wave charts were first drawn on an experimental basis in December 1952, and their development has continued on a part-time basis since then. The charts are now being drawn daily.

The need for such a chart became apparent in planning the activities of the Hydrographic Office Acoustic, Meteorological, Oceanographic Survey (AMOS) cruises, and for special area surveys. With such forecasts, survey work could be scheduled according to expected wave conditions, and locations chosen in the most favorable areas for operating, thereby making survey time most productive.

Requests for forecasts of wave conditions for specific projects by Fleet Commanders have increased during the past years. The wave charts became particularly valuable when the number of wave forecasts issued began to increase, since the charts made possible immediate evaluation of wave conditions for a large ocean area.

This study includes a one-week series of synoptic wave charts and 24-hour prognostic wave charts. This particular series of charts was selected for presentation because of the high wave activity, making the relationships between the predominant wave trains and the synoptic systems generating them stand out much more clearly. Other than this, there are no features of this series which differentiate its charts from those drawn daily at the Hydrographic Office.

B. SYNOPTIC WAVE CHART

The synoptic wave charts presented in this study are based primarily upon ship observations. A small percentage of plots consists of calculated values, which are used only in areas where ship observations are sparse or nonexistent. The plots consist of wind speed and direction, wave direction, height, and period; if the ship observation contains no wave group, wind velocity and direction are plotted. The frontal systems and pressure centers are drawn in. The plotter enters all values reported irrespective of whether or not they appear reasonable. The rejection or retention of data is determined by the analyzer.

The synoptic wave charts are drawn on the basis of the 1200Z ship observations. However, the 0600Z ship observations are also included to compensate for missing or garbled 1200Z reports and to provide an indication of trend. When many ship observations are available for the same general location, the most representative observations are plotted and the rest rejected. The 0600Z and 1200Z ship observations are normally plotted in different colors for easy analysis; this series, however, was plotted in one color, according to the code indicated in the legend, for easier reproduction.

The plotted synoptic wave chart is used as an overlay on the 1230Z synoptic weather chart. The analysis procedure is conducted on a light table. First, the wave charts and associated weather charts are examined for the directions of the predominant wave trains which are then indicated by heavy arrows. An examination of all ship observations is made, and those observations which appear to be unreasonable are rejected. A few spot calculations are made for wave heights and periods as a check on the order of magnitude of reported wave heights and periods; this is especially important when very few ship observations are available making it difficult to determine the reasonableness of a report. The calculations are made using standard techniques i.e. Sverdrup-Munk (1951) Bretschneider (1951), and Pierson, Neumann, and James (1955). The areas which contain little or no ship observations must now be considered; for these areas, wave heights and periods are calculated and plotted on the wave chart.

With the arrows indicating the predominant wave trains, and the isobaric pattern on the weather chart as a guide, contour lines of equal wave height, based on the 1200Z ship observations, are sketched in; the 0600Z observations are used as a guide. The calculated wave heights are now examined to see if they fall reasonably well within the order of magnitude of the contour lines based on reported ship observations. The calculated wave heights will generally show the relative heights fairly well. If the absolute values appear to be off, the calculated heights are adjusted to fit smoothly with the contours based on ship observations. There are no isolines of wave period on the chart; this would add another set of lines to the chart complicating it unnecessarily. In addition, it has been observed that reported wave periods are not sufficiently reliable to draw reasonably good isolines of wave period. Calculated wave heights are plotted for the points which appear to be most necessary to fix the predominant features of the wave chart and where ship observations are lacking.

No detailed calculations are made for the coastal areas since it would require considerable time and effort to take into consideration the sheltering effects and limited fetches; reported coastal observations, however, are taken into consideration. Calculations of nearshore wave conditions are made only for specific forecast requirements which are usually very much localized. The indicated procedure, in its present state of development, was designed to obtain a rapid evaluation of wave conditions over a large ocean area with reasonably good accuracy.

C. PROGNOSTIC WAVE CHART

1. Principles

There are undoubtedly many ways in which the problem of producing a prognostic wave chart can be approached. The method outlined below is one of many compromises, with the major considerations being speed of analysis, considered as firmly established since at present the charts are not produced as a standard item for operational use, but rather as a basis for further developmental work.

Of prime importance, of course, is the availability of an accurate prognostic surface weather chart. Assuming such a chart is available, the calculation of wave height and period may not be a simple one since effective wind speed and direction, fetch, and duration must be determined. In many cases it is almost impossible to determine all these quantities with reasonable accuracy, and a sizeable error in any one may result in considerable error in predicted wave heights. Further, the calculation of wave heights for a large number of points would require considerable time and effort, and, in the case of the 24-hour wave prognostic chart, could reduce the usable time of the chart to considerably less than 24 hours. In this series, wave heights were calculated for points which would appear to fix the predominant features of the charts. Intermediate points were obtained by interpolation with the weather prognostic charts as a guide. This again is done with the wave prognostic chart used as an overlay on the weather prognostic chart. At present no attempt is made to differentiate between sea and swell. The problem of crossed seas and confused seas is handled on the basis of wave height, with wave direction fitting into the predominant wave trains. Where extensive areas of confused sea are reported, these areas are generally indicated as "Variable".

The actual drawing of the present wave prognostic chart is not done with as straightforward a method as indicated above. The problem of moving fetches is constant, and not an easy one with which to cope. This problem becomes especially important during winter conditions when fast-moving intense systems are continually present in the North Atlantic. As a partial solution to this problem, an attempt is made to maintain continuity from chart to chart whenever possible. Consider the case of a system moving at a reasonably constant speed and maintaining a reasonably constant size and intensity. If the 24-hour prognostic weather chart indicates no appreciable departure from the above mentioned conditions, it is reasonable to assume that the wind field will generate waves closely approximating those presently observed. With appropriate corrections for any changes in the characteristics of the system it is possible to extrapolate into the future the wave conditions associated with a particular weather system. This is done whenever possible, even though it is realized that at present considerable subjectivity enters this phase of the prognosis. However, this same subjectivity is quite often met with in determining effective wind speed, fetch, and duration when calculating wave heights for selected points. The basis for this method is a knowledge of what a system is doing insofar as waves are concerned and corrections observed wave heights according to expected changes in the generating system. Much more work needs to be done in this respect. At the present time, such a prognosis is most accurate when made by personnel who have observed a great number of cases of synoptic weather systems and their associated wave systems.

Although the preparation of the synoptic wave chart involves the calculation of wave information, the bulk of the chart can be drawn on the basis of ship observations. The calculated information and the observations can both be corrected to fit the general wave pattern where necessary, resulting in a fairly accurate wave picture of the ocean area under consideration. During the preparation of the prognostic wave chart, no observational guides are available; every point on the chart must be predicted.

2. Example

As an example of the steps necessary in preparing a prognostic wave chart, the prognostic wave chart, verifying time 1230Z 12 January, figure 10 is used. The basic principles described in C-1 will be carried through. The prognostic wave chart is based on the 30-hour weather prognostic chart verifying time 1230Z, 12 January 1954 and the synoptic wave chart of 1230Z, 11 January 1954. It should be noted that the prognostic weather chart provides the forecaster only with the expected conditions for a specific time 24 hours into the future. This is insufficient information with which to establish the wave field for this time. The forecaster must establish the complete wind history for the 24-hour period. In the present example this is done in six-hourly intervals for the forecast period. The particular interval of time chosen will depend upon the expected variability of the wind field.

The following steps form a basic procedure for the construction of a prognostic wave chart: (1) Selection of the points for which wave information should be calculated in order to fix the predominant features of the prognostic wave chart. (2) Evaluation of the wave field as related to the synoptic weather systems and as indicated by the latest synoptic wave chart. (3) Integration of (1) and (2).

A general analysis of the prognostic weather chart will indicate the predominant fetch areas and those areas that show a minimum of wave activity. The centers of these areas will fix the predominant features of the prognostic wave chart. A sufficient number of points is now selected to provide the detail necessary for drawing the prognostic wave chart. Wave plots are calculated for these points using the form of table 1 as a guide. The prognosticated wave values are entered on the prognostic wave chart and the prognosticated frontal positions are drawn in. Isopleths of wave height are sketched in; a height interval of three feet is used at present.

In the evaluation of the synoptic wave chart, the following are noted: (1) the positions and orientation of the major wave trains, (2) the positioning of the wave trains with respect to the frontal systems, (3) distribution of heights within the trains, and (4) the history of the development of the trains as indicated by previous synoptic wave charts. Such an evaluation of the synoptic wave charts indicates the trend in the development and decay of the predominant wave trains. The established trend forms the basis for carrying the continuity into the forecast period.

The final form of the prognostic wave chart is determined by the integration of the calculated wave values and the established trends. This procedure becomes especially important in areas where wind direction and velocity show considerable variability. Under such conditions calculations are subject to large inaccuracies. The isopleths of wave height which have been sketched in are now modified to conform to the past and prognosticated trends. The prognostic wave chart is completed with graphic symbols as indicated on figure 2.

Table 1 represents a convenient working form and tabulation sheet for data necessary to carry through the individual wave forecasts for the selected points. The step of selection of points can be eliminated by establishing a

permanent numbered grid covering the entire chart area. Column 2 lists the wave information appearing on the latest synoptic wave chart, in the present case, the 1230Z 11 January 1954 chart. Columns 3, 4, and 5 contain the predicted wind history, at 6-hourly intervals during the forecast period. Column 6 contains the predicted wind values as calculated from the prognostic weather chart. The wind velocities are calculated on the basis of this geostrophic wind scale, with appropriate corrections made for isobaric curvature and sea-air temperature differences. Column 6 also contains the predicted wave information which will be plotted on the prognostic wave chart.

D. PRESENTED CHART SERIES

The series of charts presented in this study are typical of the Atlantic Ocean during winter, and show wave heights normally associated with moderately intense storms. From a meteorological standpoint, the synoptic situations in this series are characterized by blocking action over the extreme eastern portion of the Atlantic Ocean (not shown) which resulted in the storms appearing off the east coast of the United States being deflected toward the north-northeast, and which also resulted in development of a strong pressure gradient southward from Greenland. This condition prevailed until 11-12 January, after which time the blocking action relaxed, the Azores-Bermuda high intensified, and the North Atlantic storms followed a more easterly track.

One important part of the analysis of a wave chart and the preparation of a prognostic wave chart is the association of the predominant wave trains with the synoptic weather systems generating them; therefore, a bried analysis of the presented series of charts will be made with this point in view. The wave prognostic charts are based on the WBAN 30-hour prognostic charts, verifying time 1230Z.

Figure 1 is the wave chart for 1230Z, 7 January 1954 and shows two predominant wave trains associated with the frontal system extending generally southward from the vicinity of Nova Scotia. One train is associated with the southerly flow ahead of the cold front and the other with the northwesterly flow behind the front. This positioning of wave trains is typical of all such systems. Figure 2 is the 24-hour prognostic wave chart based on figure 1. The prognostic wave chart shows the continuation of both wave trains with an increase in wave heights corresponding to the expected increase in the intensity of the frontal system. To a large extent, the wave heights appearing on the prognostic chart are calculated using the wave heights appearing on figure 1 as a starting point. Figure 3 is the verification for figure 2. It shows the existence of both wave trains with prognosticated wave heights agreeing reasonably well with those reported. The major error is one of displacement of the axis of the wave trains; this is a common error experienced in drawing the prognostic wave charts.

Figure 4 is the 24-hour prognostic wave chart, verifying time 1230Z, 9 January 1954; figure 5 is the verifying chart for that time. It can be seen that the prognosticated sea conditions ahead of the front agree satisfactorily with the observed with respect to wave heights and direction and position-

ing of the wave trains. Behind the front, however, the prognosticated axis of the wave train is too far north and the area covered is too small. Under any verification system, this section of the prognostic chart must be considered unsatisfactory. Following the same frontal system on figures 6 and 7 the prognosticated and observed sea conditions show satisfactory agreement.

Figures 6 and 7 also show the development of a new major wave train off the east coast of the United States. Figures 8 through 13 show the continued development of sea conditions associated with this system; the agreement between the prognostic wave charts and the wave charts can be considered satisfactory.

A brief scanning of figures 1 through 13 will undoubtedly give the observer an insight into the nature of the sea surface that would be difficult to obtain by any other type of presentation for an ocean area of the size considered in these charts.

E. RESULTS AND CONCLUSIONS

The synoptic wave charts and wave prognostic charts are in their initial stage of development; their deficiencies are many and fully recognized. However, even in their present state they have been found to be of considerable value. First, the charts give an excellent picture of wave heights and directions over an area as large as the North Atlantic Ocean; second, the charts are a guide to the order of magnitude of wave heights for detailed forecasts for specific locations; third, the charts make easier the forecasting of swell since the wave trains are outlined clearly as are conditions in the generating area.

Shore installations would benefit considerably from the synoptic and prognostic wave charts in that the directions and heights of the predominant wave trains in the open ocean will be clearly indicated. This would be very useful as a tool for the prediction of swell approaching the shore installation and make possible more accurate prediction of surf conditions.

It should be pointed out here that the accuracy and general information that can be obtained from such wave charts depends upon the effort put into them. One major problem in this respect is the justification of increased effort in terms of time, since any increase in time required to produce a 24-hour prognostic wave chart will reduce its effective time and its overall value.

From the standpoint of studying ocean waves and the systems generating them, the wave charts are very revealing. A better understanding is being obtained of wave characteristics in front of, in, and behind frontal zones; the distribution of wave heights associated with synoptic systems; wave heights generated by wind fields of varying curvatures; relationships between swell and wave conditions in generating areas; and effects of changing wind direction on wave trains. Such problems are studied more easily when a synoptic picture of wave conditions over a considerable area is available. In addition, a picture presentation of wave conditions for large areas of the ocean is much more useful and more easily interpreted

than any word or number code message can ever be.

It is believed that this type of presentation of ocean wave conditions would be of considerable value to both military and commercial interests

F. RECOMMENDATIONS

A synoptic presentation of wave conditions, as shown on the wave chart and the wave prognostic chart, appears to be the best method of presenting wave conditions over large ocean areas. This makes the preparation of individual wave forecasts unnecessary when numerous using agencies are involved. This one feature of the wave charts makes them ideally suited for facsimile transmission either as the entire chart or as sectionals. The usefulness of areal wave intelligence to a military user transmitted by facsimile or by canned map is obvious.

Although the coastal areas have, in general, been neglected in the present wave charts, they need not be. There are several wave-reporting stations along the east coast of the United States whose reports will be included on the wave charts as soon as arrangements, now underway, are completed. More such stations taking both visual and instrumental observations should be activated so that a reasonable coverage of the east coast would be available. This information, if sufficient coverage can be obtained, would be of considerable value to shore installations and activities operating near shore.

More work is necessary to decrease the time required to produce a wave prognostic chart. This would involve further development of the methods already discussed, application of the latest developments in the forecasting field, and efficient design of new procedures and techniques to make these charts a production item with acceptable accuracy.

The synoptic wave charts and the prognostic wave charts already have been proved to be of considerable value. With further developmental work they have the potential of becoming a useful addition to any ocean forecasting activity.

TABLE 1

OBSERVED AND FORECAST WIND AND WAVE CONDITIONS (11 and 12 January 1954)

1	2					3			4			5			6								
	Observed Wind and Waves 1230Z 11 Jan.					Predicted Wind 1830Z 11 Jan.			Predicted Wind 0030Z 12 Jan.			Predicted Wind 0630Z 12 Jan.			Predicted Wind 1230Z 12 Jan.				Predicted Waves				
Position	F	V	H	T	Dir.	F	V	Dir.	F	V	Dir.	F	V	Dir.	F	V	Dir.	Dur.	V_1	H	T	Dir.	
35N 75W	250	17	6	-	SSW	100	17	N	100	19	NW	100	17	NW	70	17	NW	18	17	5	5	NW	*
30N 75W	175	18	7	6	SW	175	18	SW	200	16	NW	250	13	NW	300	13	NW	12	13	2	3	NW	*
35N 70W	200	28	11	6	SSW	175	24	SW	200	24	NW	350	22	NW	350	21	NW	12	22	10	7	NW	*
30N 70W	150	20	8	6	S	150	18	SSW	150	22	SSW	150	21	SW	175	21	SW	18	21	9	6	SW	
25N 70W	200	17	5	-	SE	200	16	SSE	175	14	SSE	175	14	S	175	15	S	18	14	3	4	S	
40N 65W	175	18	5	7	NE	150	14	SE	150	15	SSW	175	21	W	200	21	WNW	12	21	9	6	WNW	*
35N 65W	175	28	14	7	SSW	175	28	SW	200	29	SW	250	32	SW	250	32	SW	24	32	21	10	SW	
40N 60W	150	18	6	5	NE	200	24	SW	250	30	SW	250	38	SW	250	42	WSW	22	38	22	9	WSW	*
30N 60W	100	14	3	2	S	150	16	S	150	20	SSW	150	20	SW	150	21	SW	12	21	9	6	SW	
25N 60W	300	12	2	2	E	250	14	SE	250	12	S	200	12	SSW	200	13	SSW	18	12	2	3	SSW	*
55N 55W	125	22	8	-	W	125	24	WSW	125	22	WSW	125	21	SW	120	21	SW	24	21	9	6	SW	
45N 55W	100	16	5	-	NNE	150	18	ENE	250	24	E	350	28	ESE	350	30	SE	24	30	22	9	SE	*
40N 55W	200	20	9	6	SW	250	25	SW	270	27	SW	300	32	SW	300	33	SW	24	32	24	10	SW	
35N 55W	200	14	4	4	SW	200	18	SW	250	24	SW	250	28	SW	300	31	SW	18	28	17	8	SW	
50N 50W	175	22	10	-	WNW	150	22	WNW	150	18	NW	150	12	NW	150	9	SE	6	9	1	2	SE	*
35N 50W	150	14	5	6	SW	150	16	SSW	150	18	SSW	150	20	SW	200	21	SW	18	21	9	6	SW	
30N 50W	100	15	5	6	E	150	16	E	150	16	E	150	17	ESE	150	13	S	8	16	5	5	S	*
25N 50W	100	12	2	-	E	100	14	E	100	11	E	175	9	E	200	9	E	24	9	1	2	E	
55N 45W	200	22	9	-	WNW	150	24	WNW	150	24	W	150	23	WNW	150	23	WSW	12	23	11	6	WSW	
45N 45W	200	30	15	-	WSW	200	22	SW	150	16	SSW	150	16	SSE	100	18	SE	12	17	5	5	SE	*
35N 45W	150	16	8	-	SW	150	16	SW	150	16	SW	175	16	SW	200	15	SW	24	16	5	6	SW	
30N 45W	150	14	4	4	NE	150	12	ESE	150	13	ESE	150	14	SE	150	12	S	6	12	2	2	S	
50N 40W	300	26	11	-	WNW	300	22	WNW	300	14	W	200	10	WSW	100	8	SW	6	8	1	1	SW	*
45N 40W	200	28	15	-	WSW	300	22	WSW	250	14	S	150	12	SSE	100	9	SE	12	9	1	2	SE	*
40N 40W	200	18	10	7	WSW	150	14	E	150	14	S	150	12	S	150	13	S	-	12	3	2	S	*
35N 40W	150	18	9	-	E	150	14	E	150	14	SSE	150	14	S	150	15	S	12	14	3	4	S	*
55N 35W	150	22	10	-	SSE	150	20	SSW	200	22	SW	200	20	SW	150	20	SW	24	20	8	6	SW	*
50N 30W	250	18	13	-	SSW	200	15	WSW	150	13	WSW	150	10	SW	150	9	SW	6	9	1	2	SW	
45N 30W	300	21	11	8	W	250	16	WSW	200	14	WSW	150	10	WSW	100	8	W	24	8	1	2	W	
40N 30W	150	12	7	-	NNW	150	12	NW	150	15	WNW	150	14	NW	150	14	NW	24	14	3	4	NW	
55N 25W	150	26	12	-	S	250	22	NSW	200	18	WSW	200	14	SW	200	12	SW	24	12	2	2	SW	

F = Fetch length in nautical miles

V = Wind speed in knots

H = Wave height in feet

T = Wave period in seconds

V_1 = Wind speed effective for duration

* = Wind shifts during 24-hour period

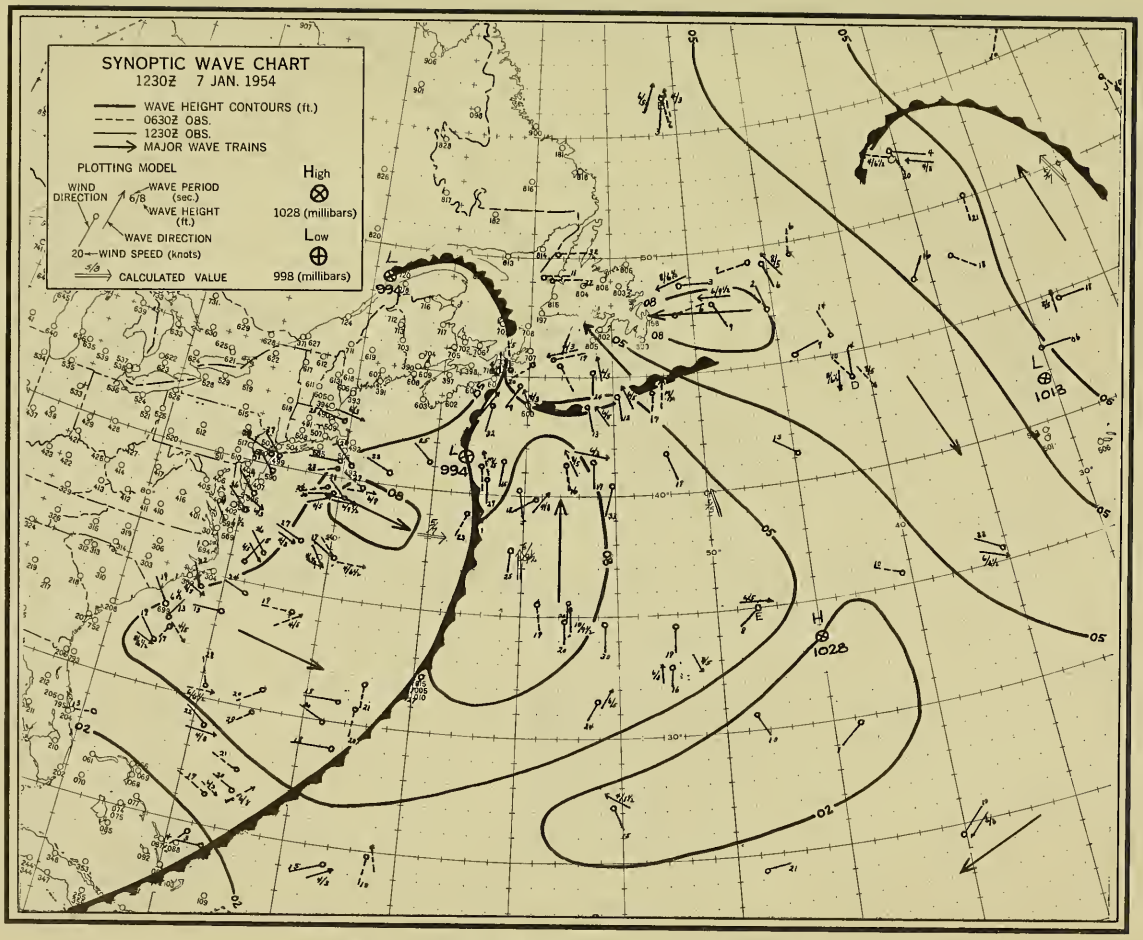

FIGURE 1. SYNOPTIC WAVE CHART 1230Z 7 JANUARY 1954

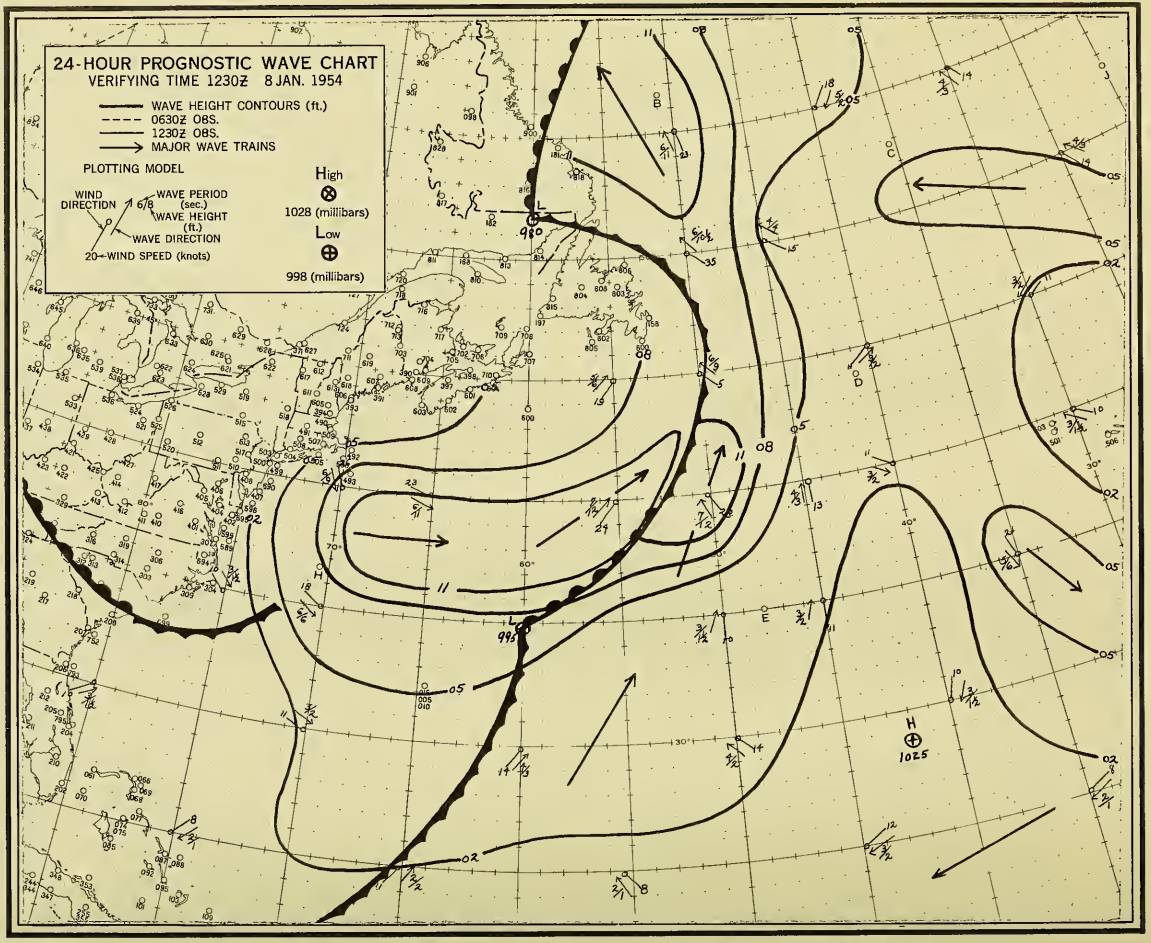

FIGURE 2. PROGNOSTIC WAVE CHART, VERIFYING TIME 1230Z 8 JANUARY 1954

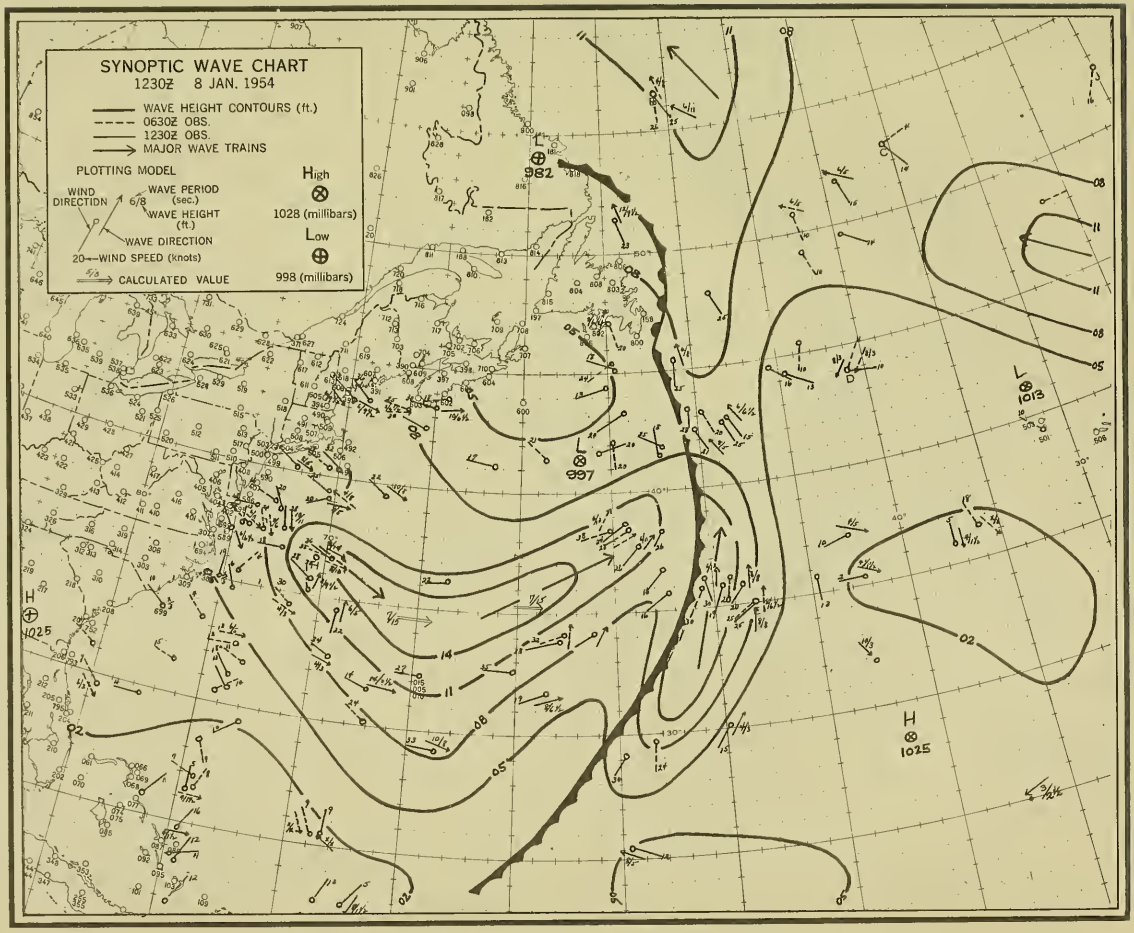

FIGURE 3. SYNOPTIC WAVE CHART 1230Z 8 JANUARY 1954

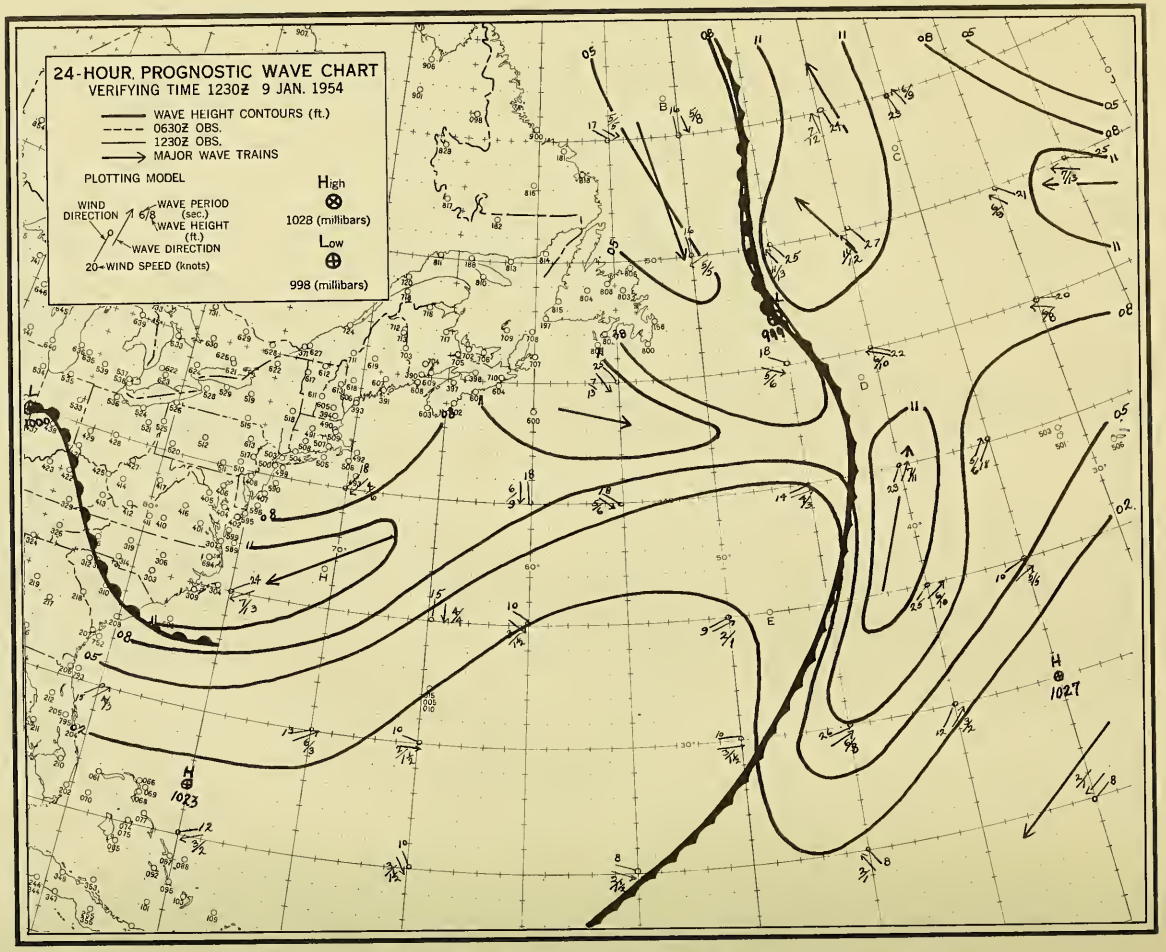

FIGURE 4. PROGNOSTIC WAVE CHART, VERIFYING TIME 1230Z 9 JANUARY 1954

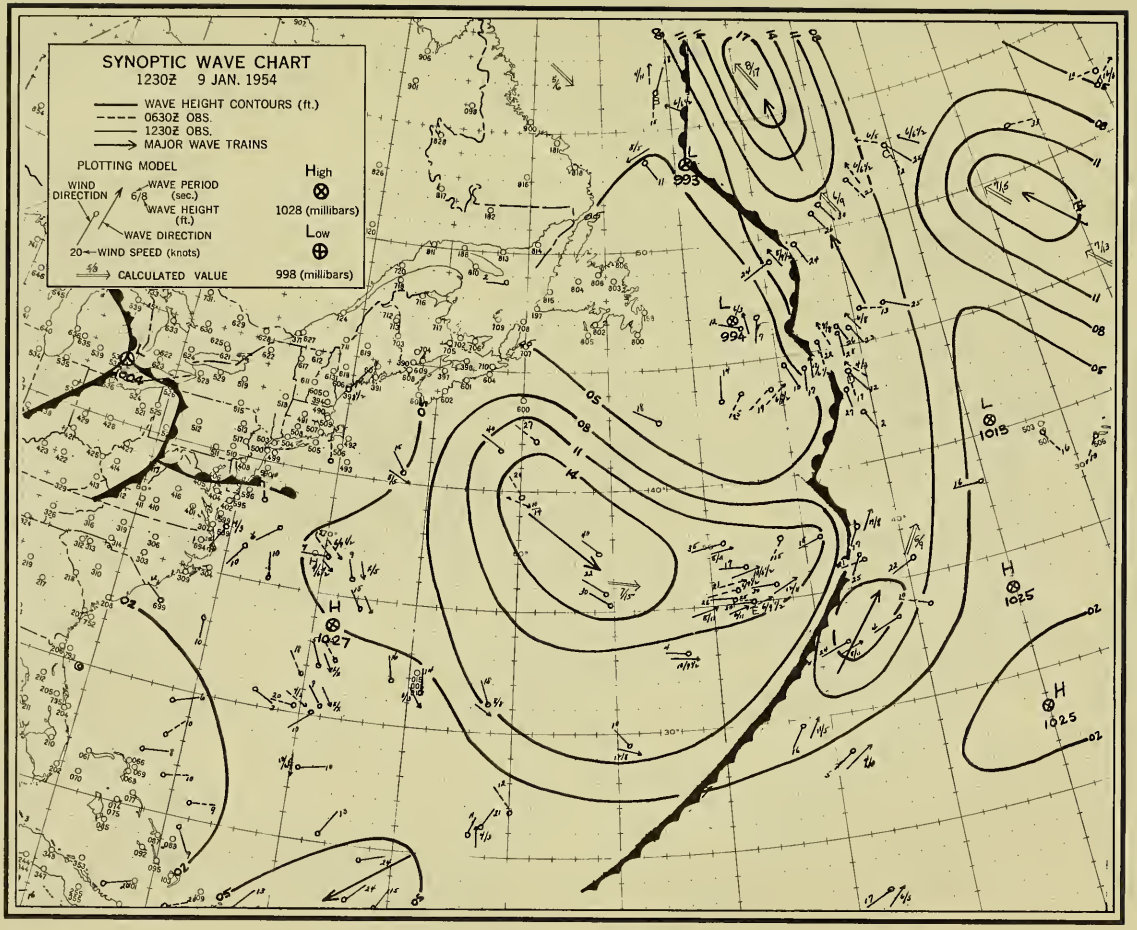

FIGURE 5. SYNOPTIC WAVE CHART 1230Z 9 JANUARY 1954.

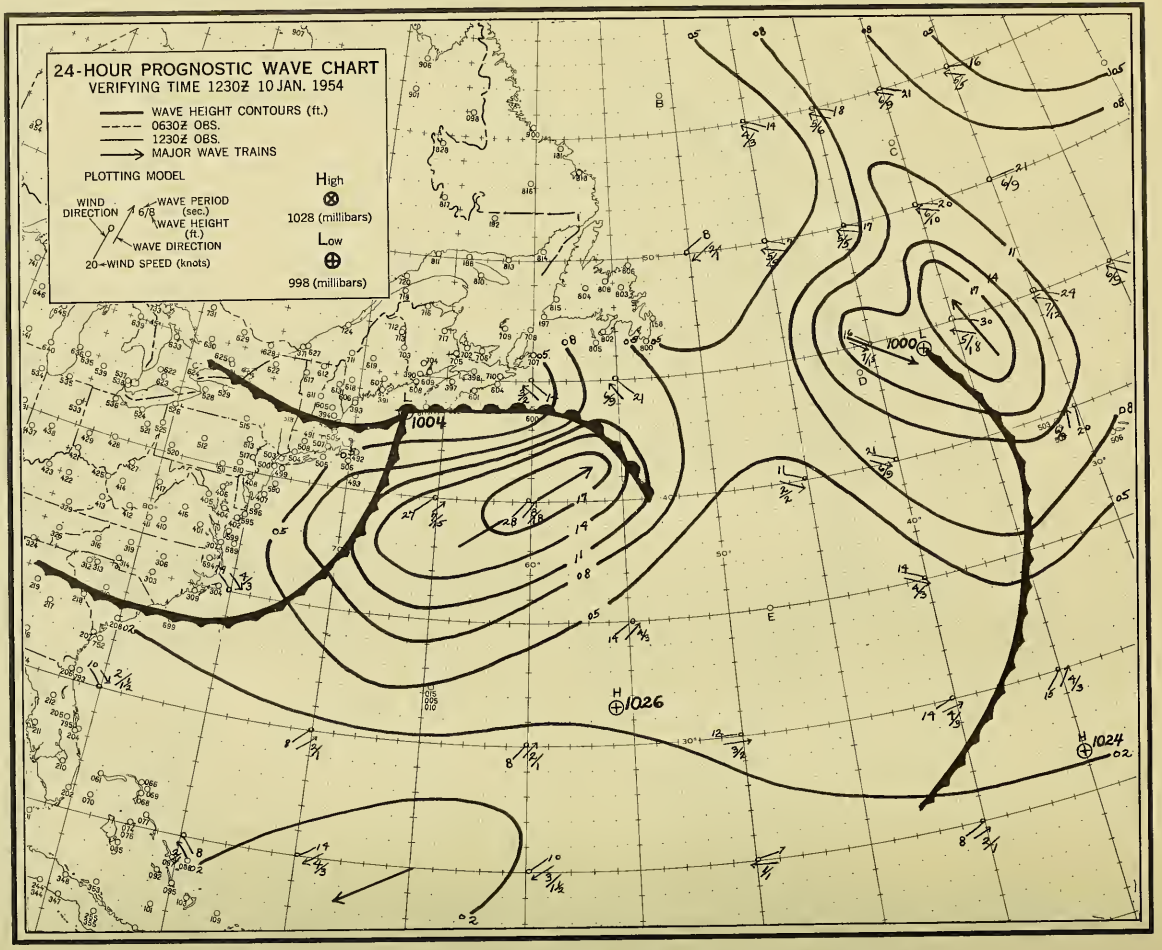

FIGURE 6. PROGNOSTIC WAVE CHART, VERIFYING TIME 1230Z 10 JANUARY 1954.

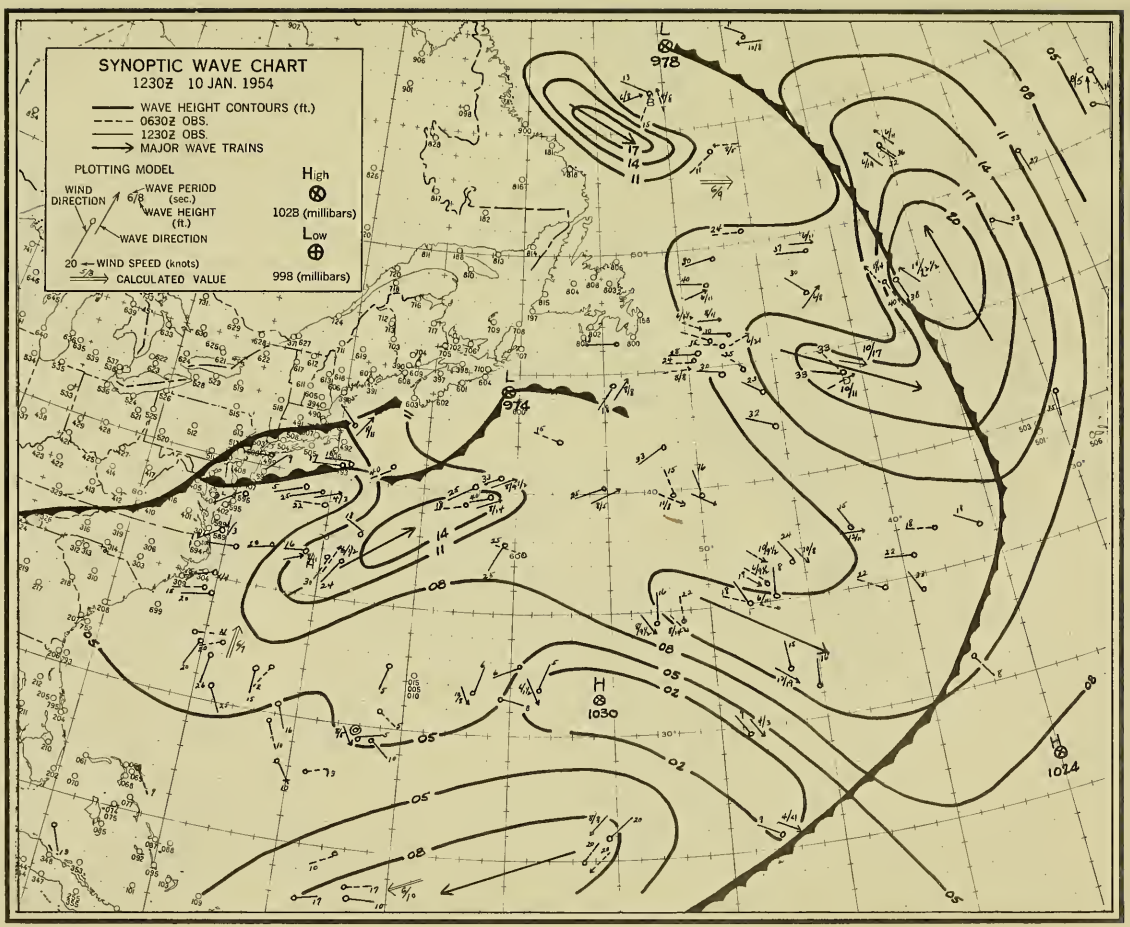

FIGURE 7. SYNOPTIC WAVE CHART 1230Z 10 JANUARY 1954.

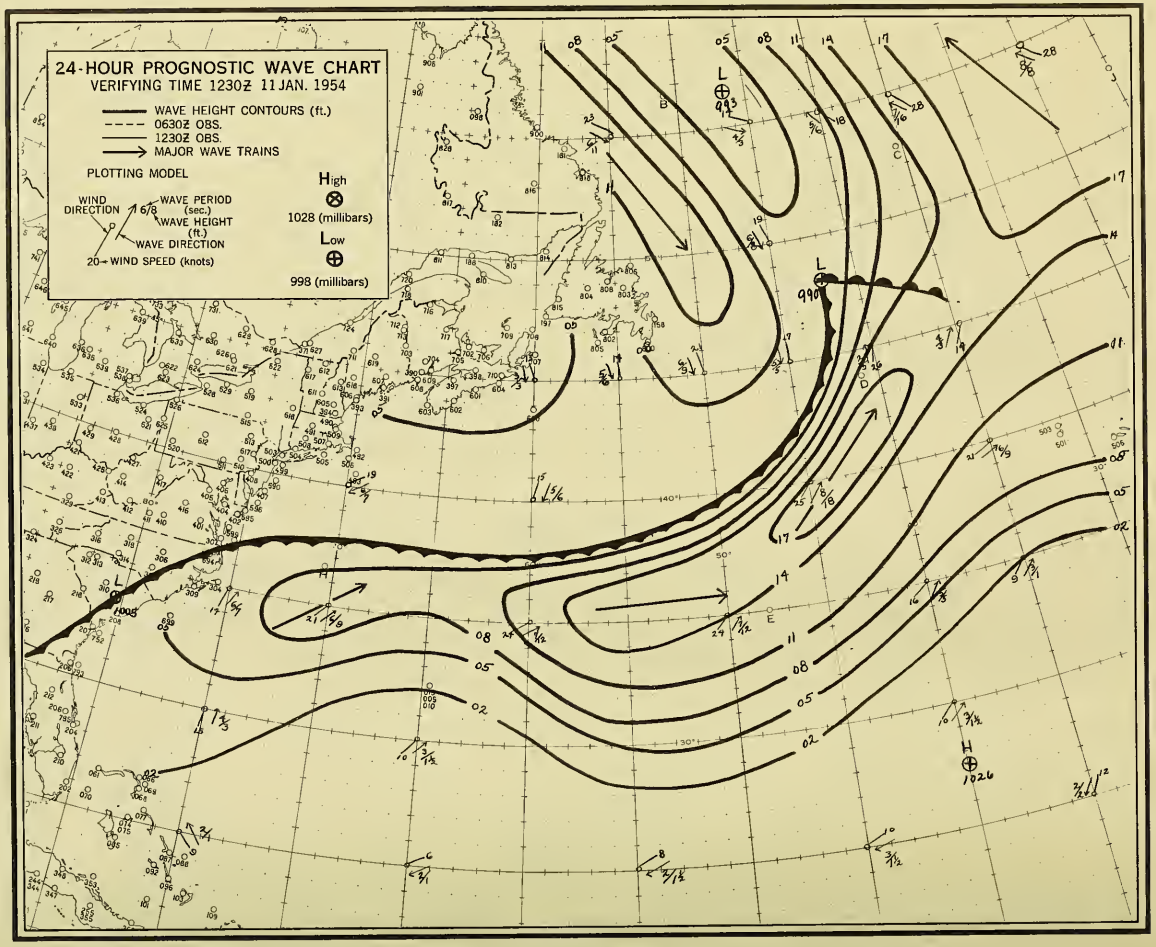

FIGURE 8 PROGNOSTIC WAVE CHART, VERIFYING TIME 1230Z 11 JANUARY 1954.

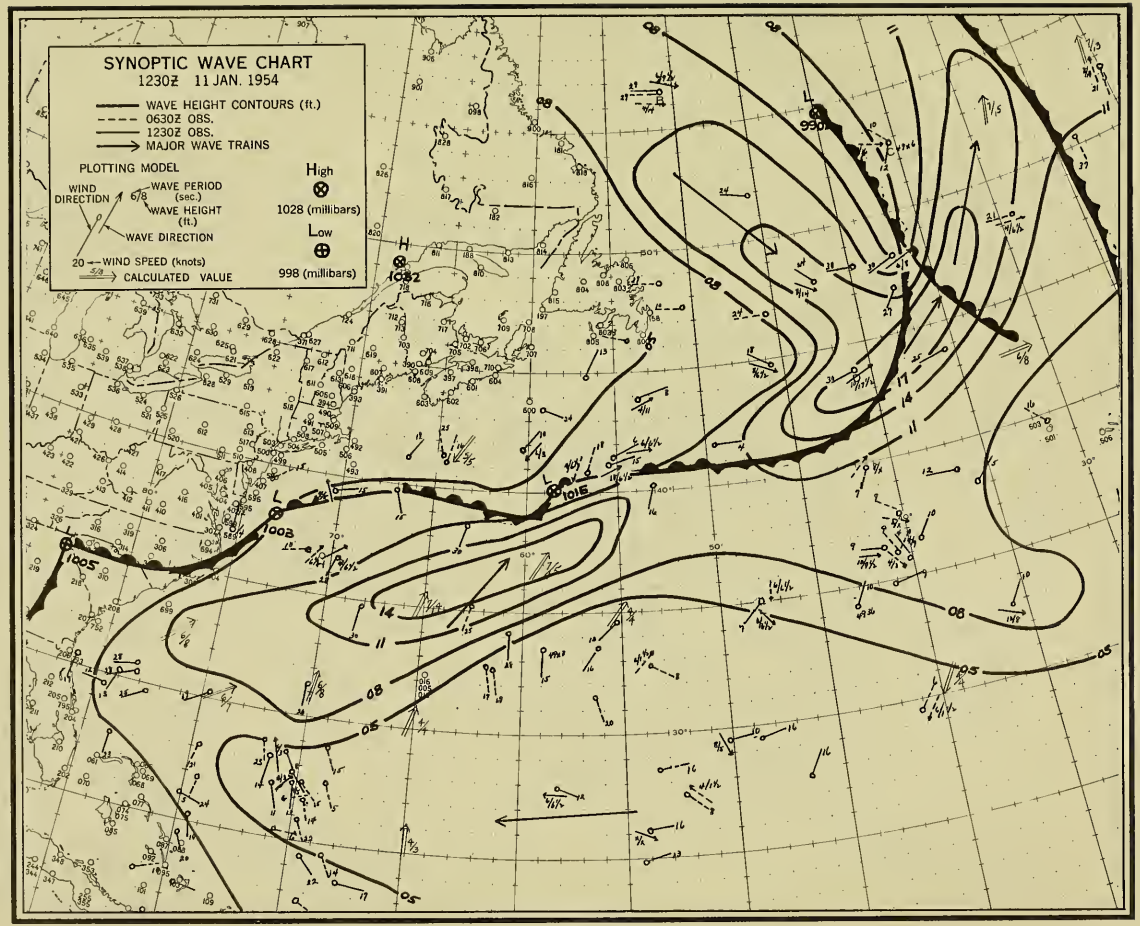

FIGURE 9. SYNOPTIC WAVE CHART 1230Z 11 JANUARY 1954

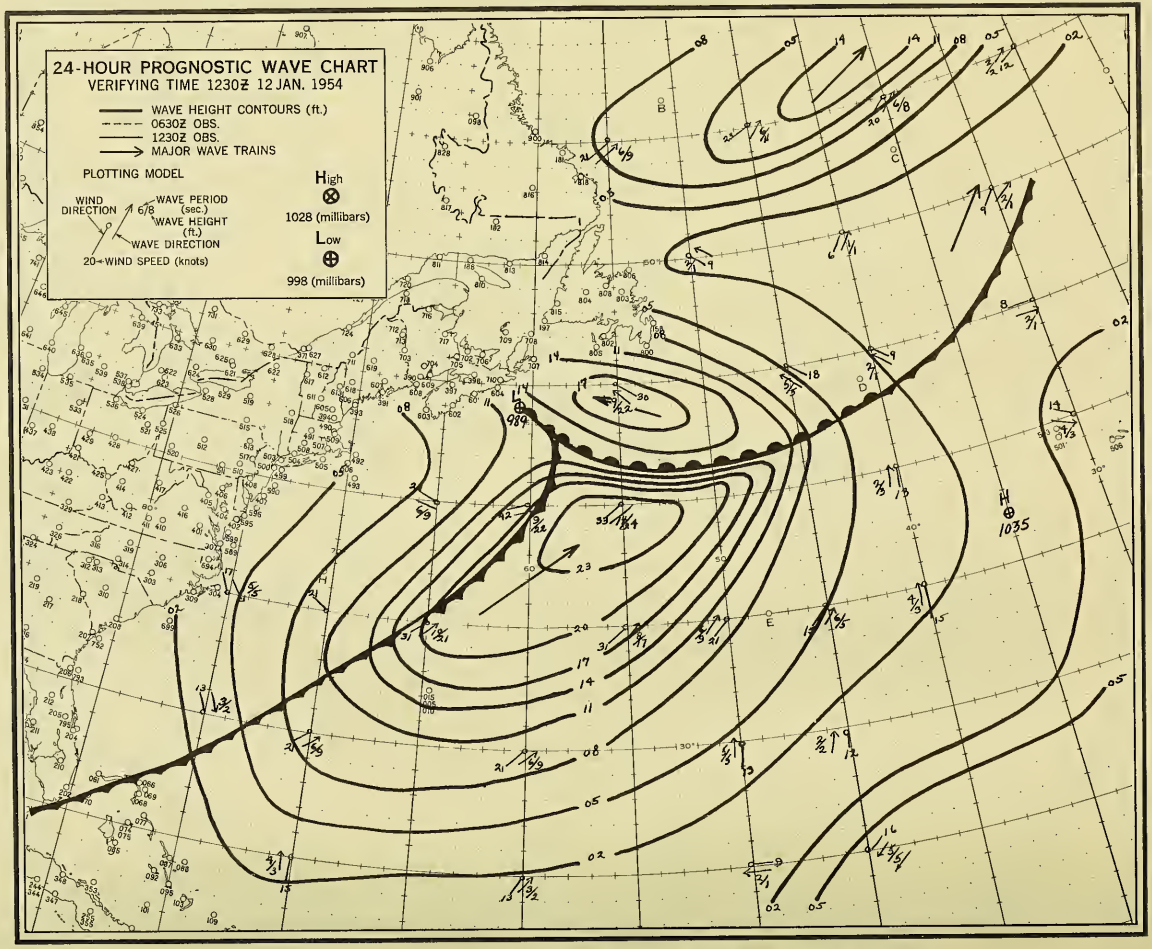

FIGURE 10. PROGNOSTIC WAVE CHART, VERIFYING TIME 1230Z 12 JANUARY 1954

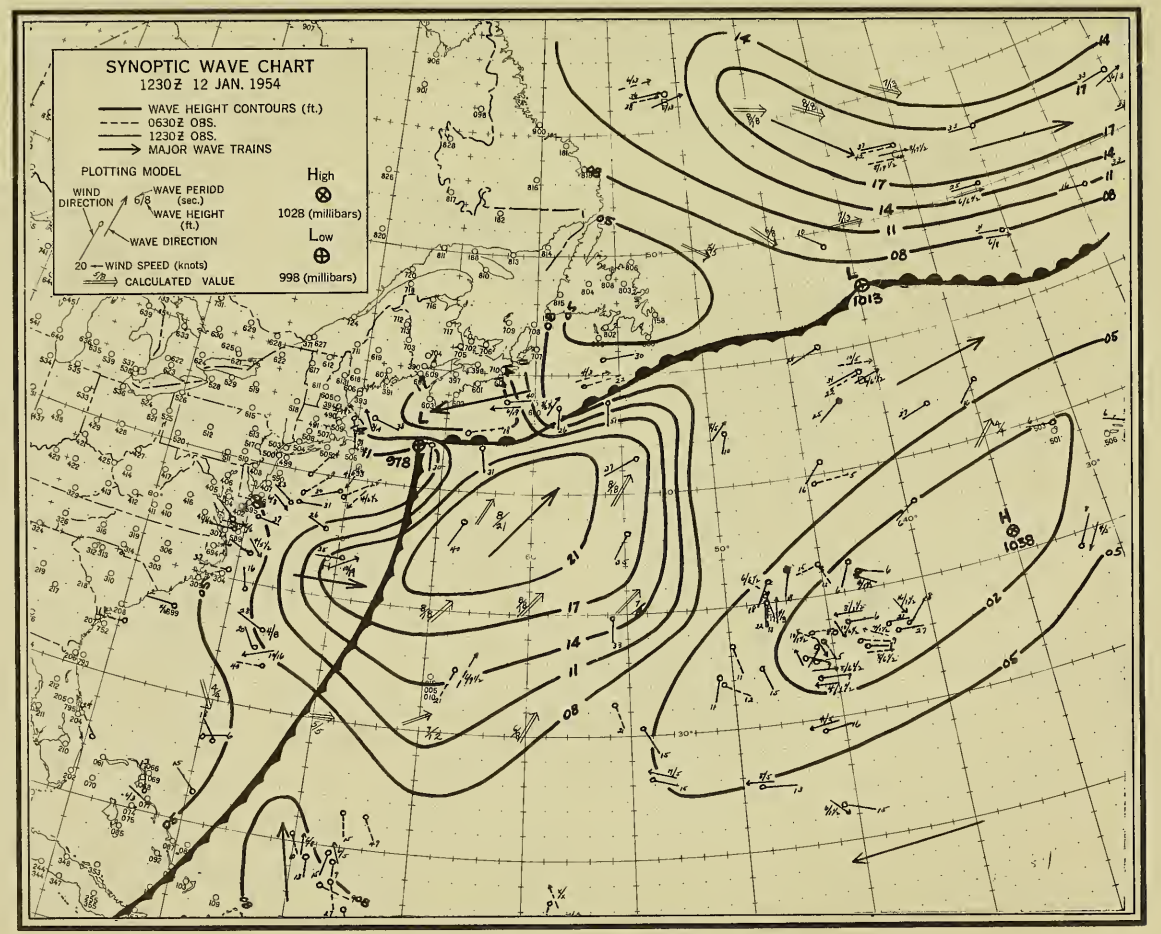

FIGURE 11. SYNOPTIC WAVE CHART 1230 Z 12 JANUARY 1954

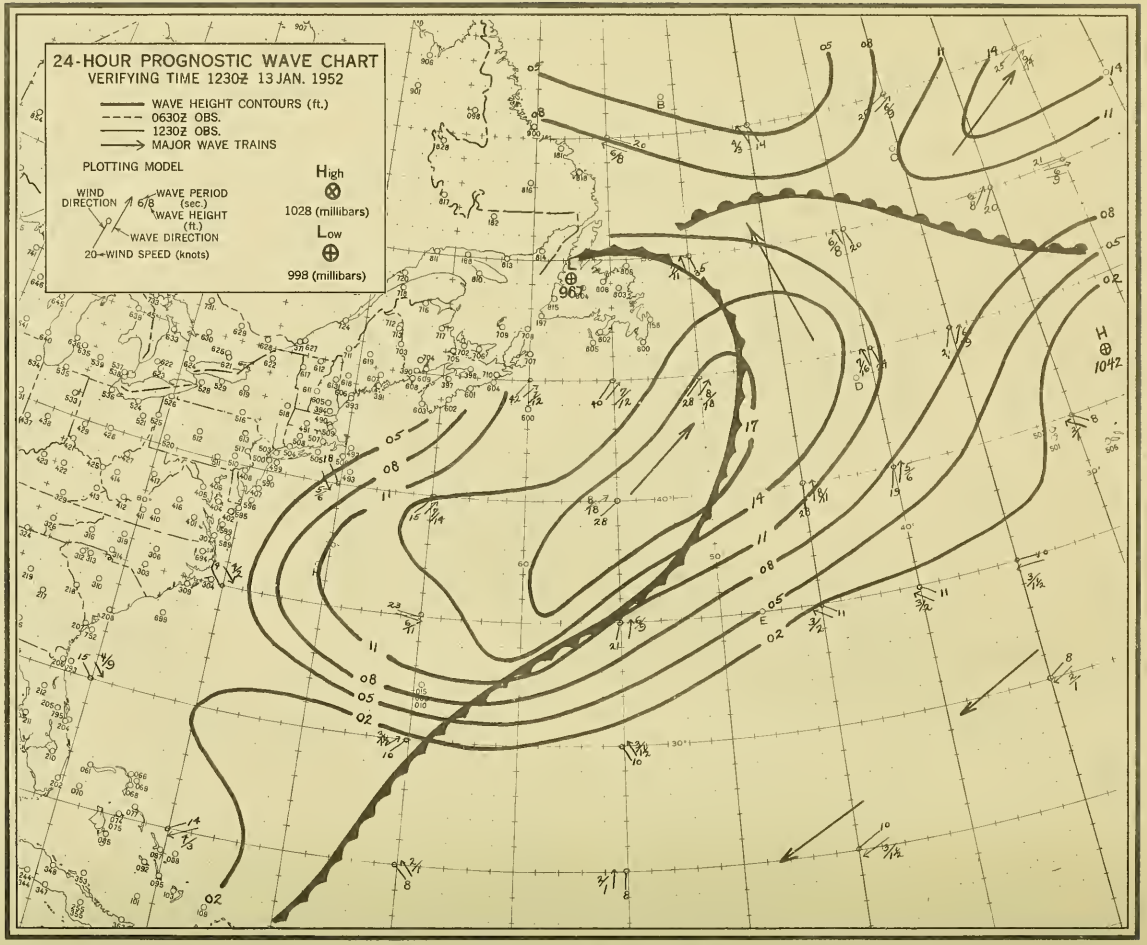

FIGURE 12. PROGNOSTIC WAVE CHART, VERIFYING TIME 1230 Z 13 JANUARY 1954

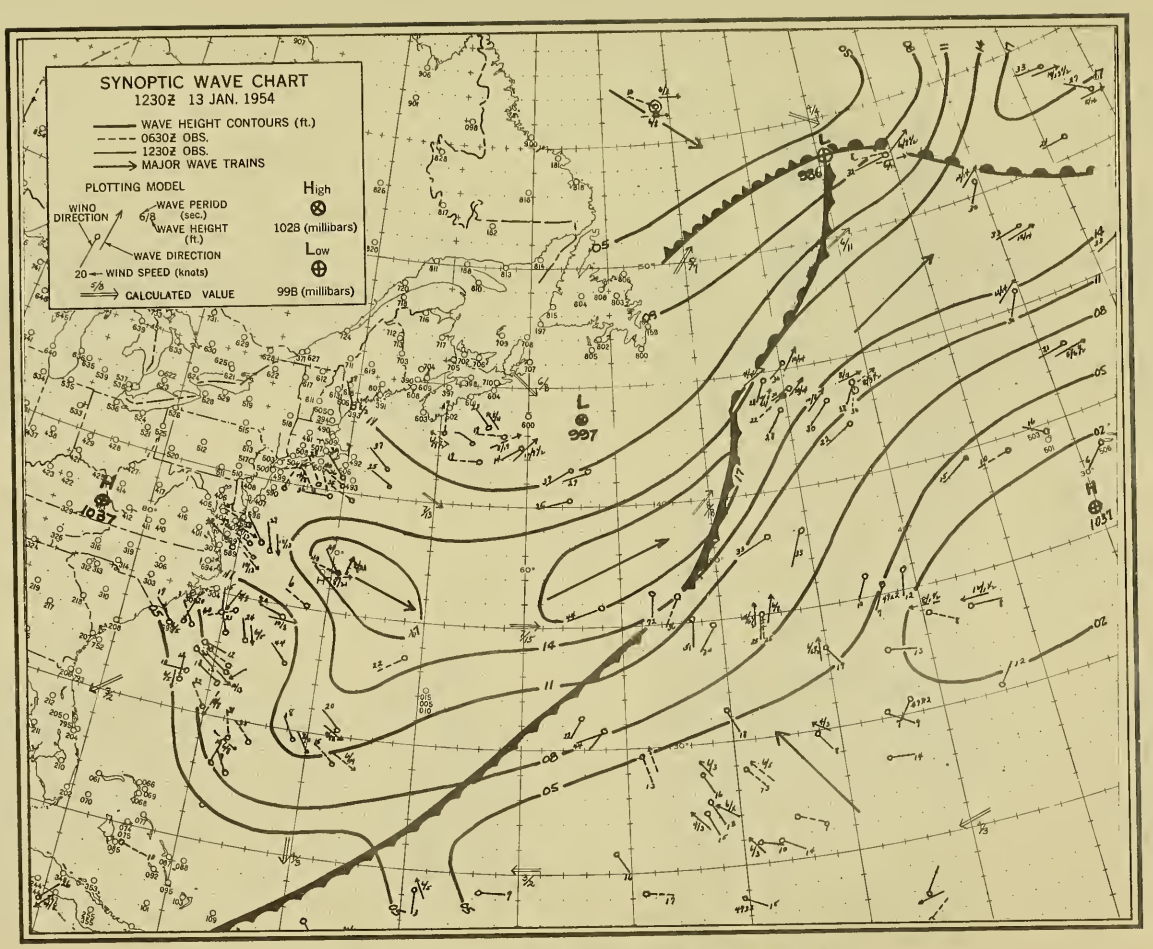

FIGURE 13. SYNOPTIC WAVE CHART 1230Z 13 JANUARY 1954

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